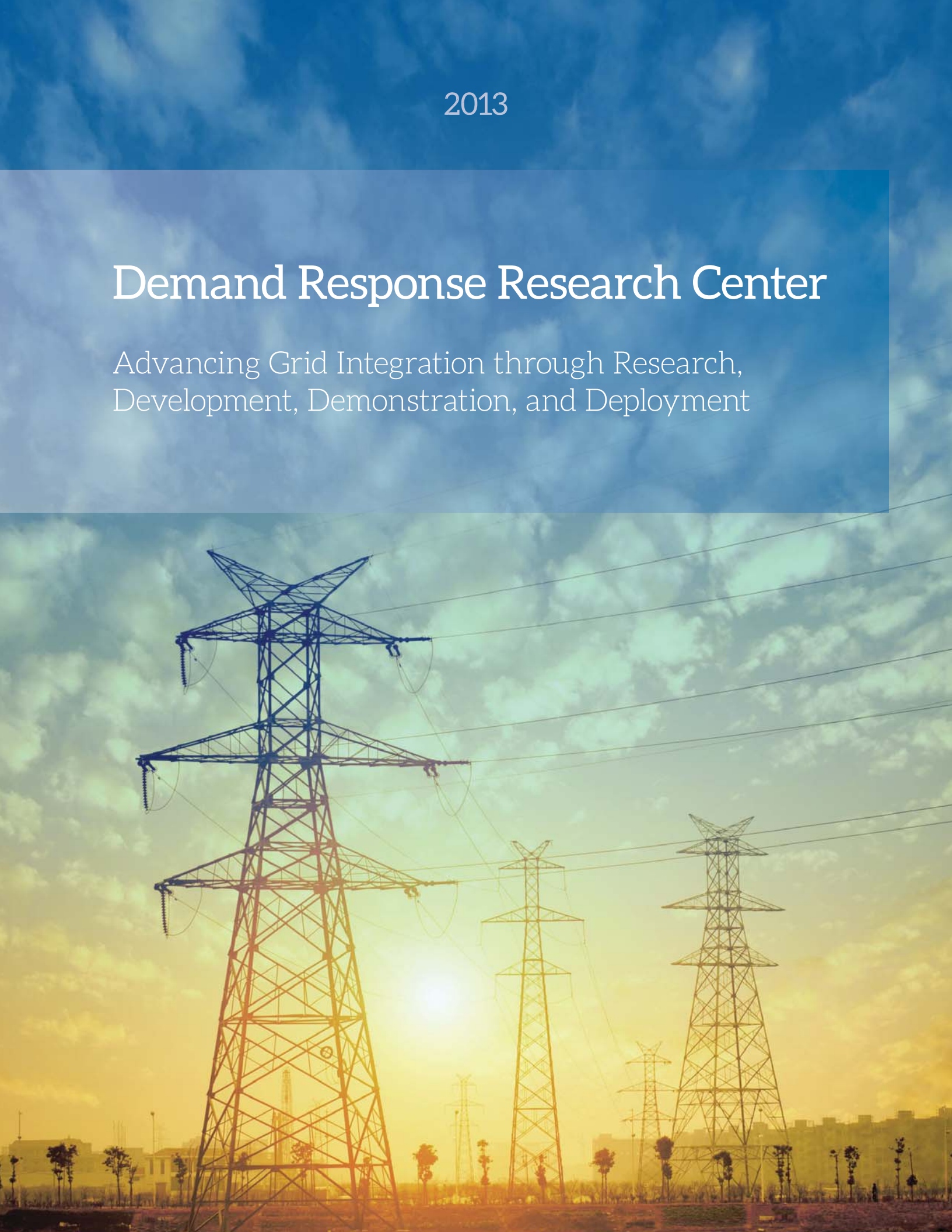


2013

Demand Response Research Center

Advancing Grid Integration through Research,
Development, Demonstration, and Deployment



Foreword

In the year 2000, the California electric system abruptly ran into a severe power shortage, requiring brownouts and rotating outages. The problem was widely blamed on inadequate forecasting, associated with flaws and transition problems in the recent switch from a vertically integrated utility structure to a novel restructured system. Power shortages were further aggravated by speculators manipulating wholesale markets for electricity and natural gas.

At that time, only major industrial customers were subject to demand charges. Most commercial and all residential customers were subject to "flat rates." They were provided no information on scarcity, information that could motivate them to reduce their electrical load by setting up air conditioning thermostats or delaying, until off-peak times, the use of clothes dryers, electric water heaters, pool pumps, and other appliances.

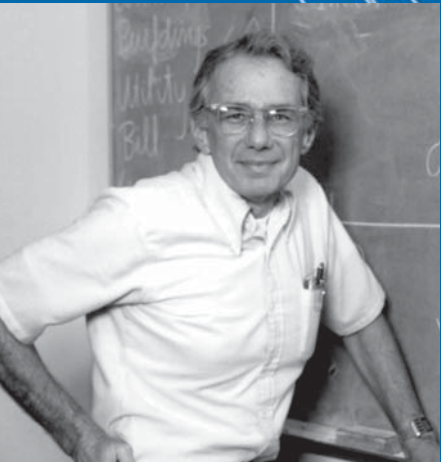
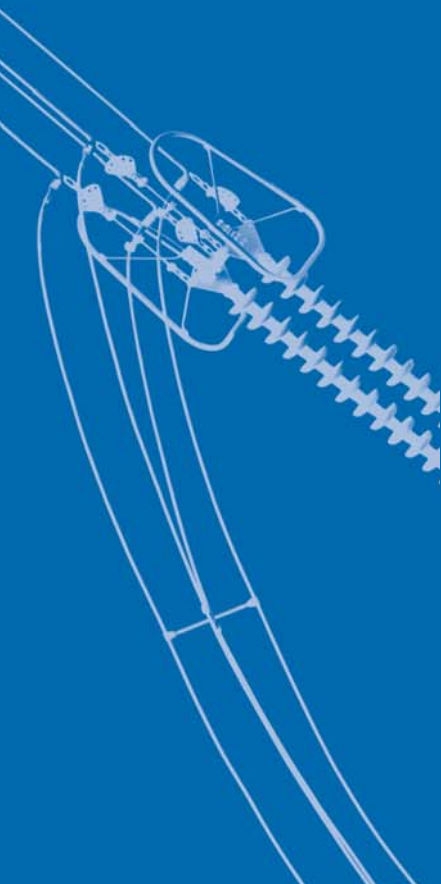
In 2000, I had just been appointed Commissioner at the California Energy Commission and was in a position to lead the modernization of this primitive system of "flat rates." We organized an interagency team to plan a smarter electric system in which every "smart meter" and control system receives from the utility, in real time, the current price of a kilowatt-hour. Further, every control system, all the way down to smart residential thermostats, can be preprogrammed automatically to respond to the current price.

In 2001, the California Legislature authorized \$32 million for 15-minute interval meters to be installed at facilities of all customers using more than 200 kW, allowing them to participate in time-of-use rates.

In 2002, the California Energy Commission (CEC) allocated funds for research on demand response, to be conducted at Lawrence Berkeley National Laboratory.

Based on the results of field tests conducted in 2003, the CEC founded the Demand Response Research Center (DRRC), housed at Lawrence Berkeley National Laboratory. In its first decade, the DRRC has become a leader in demand-response research, proliferating its ideas and its technology worldwide. It works with the private sector and international partnerships and cooperates with electric utilities, industry, and policymakers. In this report you can read about a few of DRRC's achievements and its plans for the future.

Arthur H. Rosenfeld
Distinguished Scientist Emeritus
Lawrence Berkeley National Laboratory



Executive Summary

Electrical energy is an “on demand” commodity, so the supply must always match the demand. Historically, when demand overran available supply, rolling brownouts or (worse) blackouts were the result. Demand response (DR), in which customer electric demand is reduced temporarily, can provide a strategy to mitigate blackouts as well as to help manage price spikes and improve overall grid reliability. The Demand Response Research Center (DRRC) was developed to help improve the performance and cost effectiveness of demand response. Since its inception, the DRRC has been looking for ways to enhance DR’s effectiveness, largely through improved communications between connected supply and demand on the grid and through better understanding of how buildings and other energy-consuming structures respond to operational changes arising from reductions in electric energy use. These efforts include:

- Finding new and better ways to automate DR so that it becomes more reliable and cost-effective over the long term.
- Finding better ways to measure load reductions in buildings and industrial loads, including more accurate baseline models.
- Exploring the limits of automation to better understand how quickly DR can be deployed to meet short-term power needs.
- Identifying and testing better ways to model building operations, plus testing and disseminating information on the best DR control strategies for reducing loads.
- Making connections between DR and energy efficiency so that these historically separate efforts can become more synergistic.
- Examining industrial, agricultural, and water processes to find flexibility that can be translated into reduced load when needed.
- Developing a common, standardized “language” to communicate DR price and signals reliably between the energy service providers and customers and support the national Smart Grid interoperability standards vision.
- Studying how DR can enhance the integration of energy systems with renewable energy sources (e.g., solar or wind), storage (e.g., thermal or electric batteries), and distributed energy resources (DERs).

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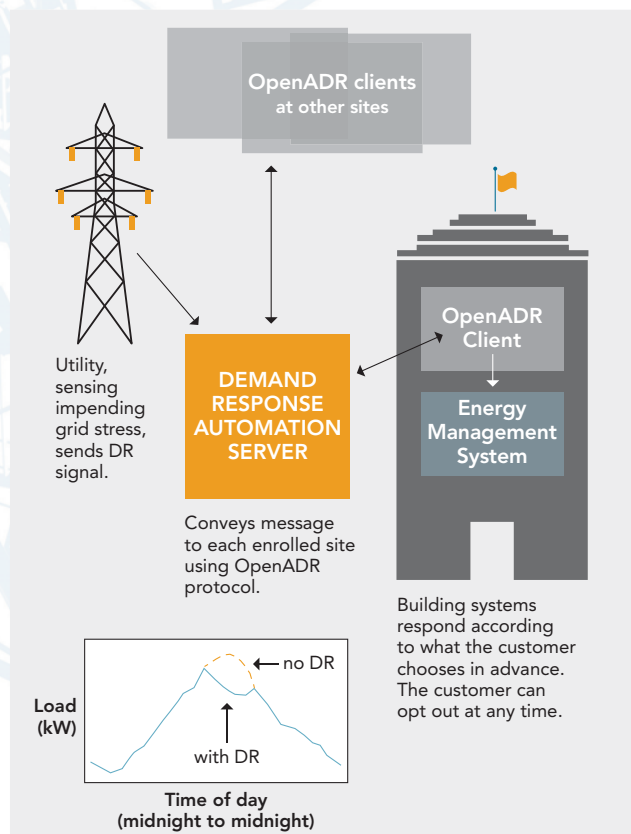
What is Demand Response?

When there is a discrepancy between electric demand and the available supply to meet that demand, something has to happen. Sometimes grid operators are able to notify potential Demand Response (DR) participants a day in advance; other times the response may be required in a much shorter time. Simply stated, demand response is an intentional modification of electricity usage by end-use customers during system imbalances or in response to market prices. It can take many forms, from postponing processes to times when overall demand is lower to modifications of ongoing processes to make them less energy intensive. DR improves electric grid reliability and reduces system operation costs by providing incentives to customers who can respond to price signals or other indicators of grid stress.

Automation

Before the establishment of the DRRC, most DR was implemented manually, except where loads such as air conditioning could be directly controlled. A phone call or fax from the utility to selected large commercial or industrial customers signaled a need for demand reduction, and those facilities capable of making reductions did so, largely by adjusting their systems by hand. Early work at the DRRC explored techniques to automate the process, finding that with the introduction of a hardware gateway box to convert utility signals to specific user-selected relay controls, participants could opt out if business or other considerations made it inconvenient to participate in DR events. This evolved to a standard specification to allow DR automation to be integrated into existing control software platforms.

Over the past decade, the DRRC has developed and deployed new technology to enhance DR automation in California, the United States, and around the world. This technology has been used to reduce both summer and winter peak demand, but also to automate DR at any hour when needed to maintain overall grid stability.



How automated demand response works.

OpenADR and the Smart Grid

During the past decade, advancements in information technology, communications, and controls have driven investments in infrastructure to effectively make the grid smarter—making it able to assess its status and need for power resources. The Smart Grid communicates with its components, transforming what was essentially a commodity market into an interactive market that can sense and resolve problems before the customer loses electricity supply. For DR, this required a consistent way to communicate grid stress. The DRRC developed Open Automated Demand Response (OpenADR), which quickly became a national standard for communicating DR signals in the United States. In fact, its adoption has shown so much promise that it is gaining traction around the world and is on track to become an international standard.

At the Lawrence Berkeley National Laboratory (Berkeley Lab) Guest House, visitors who have business with Berkeley Lab can get a comfortable night's sleep—while experiencing a living example of some of the laboratory's scientific research. The Guest House features the Demand to Grid (D2G) Lab, where appliances are controlled using DR signals and Web-based energy-visualization tools to provide information about energy choices available during DR events.

For example, a heat pump water heater (on extended loan from General Electric) in the Guest House's laundry area is part of the demonstration. It has two modes of heating—resistive heating (where a heating coil heats the water) for everyday operation, and a heat exchanger used during a DR event. The heater uses 4,500 watts of electricity during standard electric mode, powering down to 550 watts using the heat exchanger during DR events.

The Guest House also features an electric vehicle charger by Coulomb Technologies, which will switch to a reduced charging rate during a DR event. Before and during the DR event, a message is displayed on the charger's screen to let consumers know what is happening and if they have to take any action. Additional Guest House appliances that can communicate and switch to low-power operations in response to DR signals include a staff refrigerator, a washer and dryer available for guest use (also on loan from GE), programmable communicating thermostats, smart plugs, and dimmable LED lighting fixtures.

DRRC Activities and the Future

Work at the DRRC has just begun to uncover new ways that DR can be used to improve grid stability while enhancing the environment. With improvements in telemetry, DR-related communications can be made faster. This has already been tested at DRRC for use at the Independent System Operator (ISO) level, where DR has proven it can reduce peak demand quickly and reliably. The reduction of short-term peak loads when DR events are called (typically on the order of 50 to 100 hours per year) defers the need to build new peak generation plants. The DRRC believes fast DR also holds great promise for mitigating the instabilities inherent in renewable-energy sources such as solar and wind, where brief changes in sunlight or barometric pressure could otherwise translate to substantial power reductions.

Two-way grid communications also means that the marketplace itself is on the verge of transformation. DRRC's research has already begun to explore what this may mean in the future, with studies of grid-scale batteries coordinated using DR and transactive networks, in which DR communications identify the grid signals by which building operations can be cooperatively modified to maintain occupant comfort while reducing energy use at peak times.

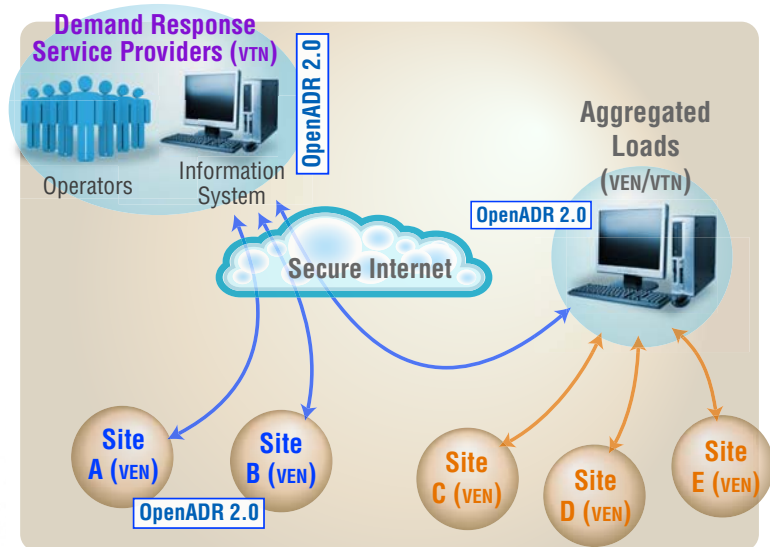
Our vision is to help create optimized, grid-aware, continuous energy management in buildings and other grid-connected elements with real-time interactions of loads and distributed energy resources that build on the capabilities developed over the past decade at DRRC. While traditional DR has concentrated on reducing peak loads in buildings, we envision a future where the load will be more dynamic, changing spatially and temporally, thereby requiring more dynamic participation of flexible resources using tools developed by the DRRC.



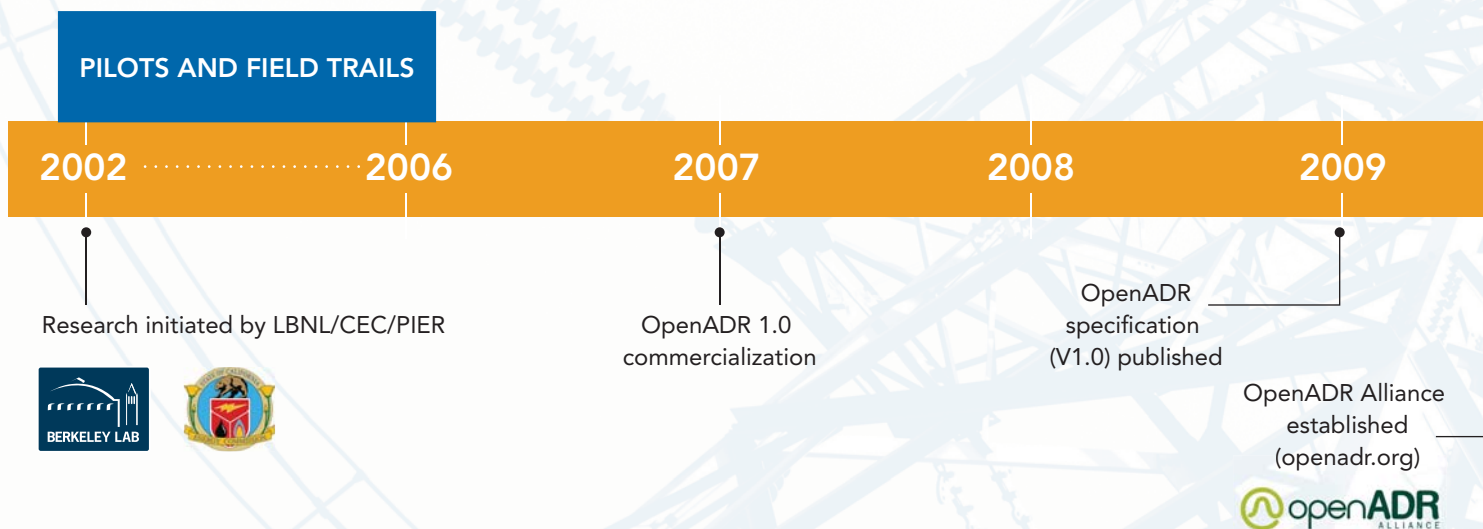
Photovoltaic panels at the Santa Rita Jail in Dublin, CA.

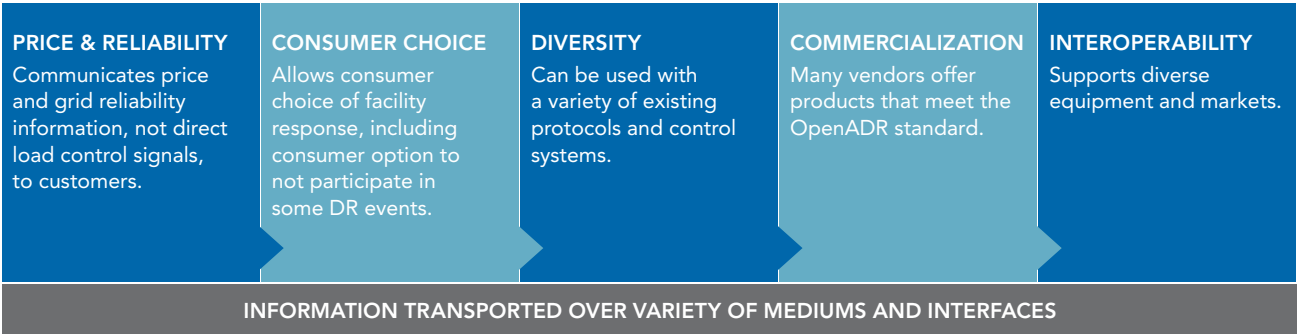
Integrated Energy Technologies and Systems

- **Problem:** For demand response to become ubiquitous, there must be clear communication between energy-supply providers and customer loads.
- **Solution:** DRRC led the development of a nonproprietary, open standardized communications specification to automate DR. OpenADR facilitates the reliable, cost-effective automation of electricity price and grid-reliability signals to enable DR. It allows electricity providers to communicate DR signals directly to existing customers using a common language and existing communications such as the Internet.
- **Benefit:** OpenADR, now a national standard, reduces technology costs and allows companies across the United States to embed the communication system in their control software at minimal cost—letting consumers control their energy costs.



OpenADR2.0 works via nodes (virtual top nodes, or VTN, act as servers, whereas virtual end nodes, or VEN, act as clients). When used by aggregators, an OpenADR2.0 node may perform both functions.



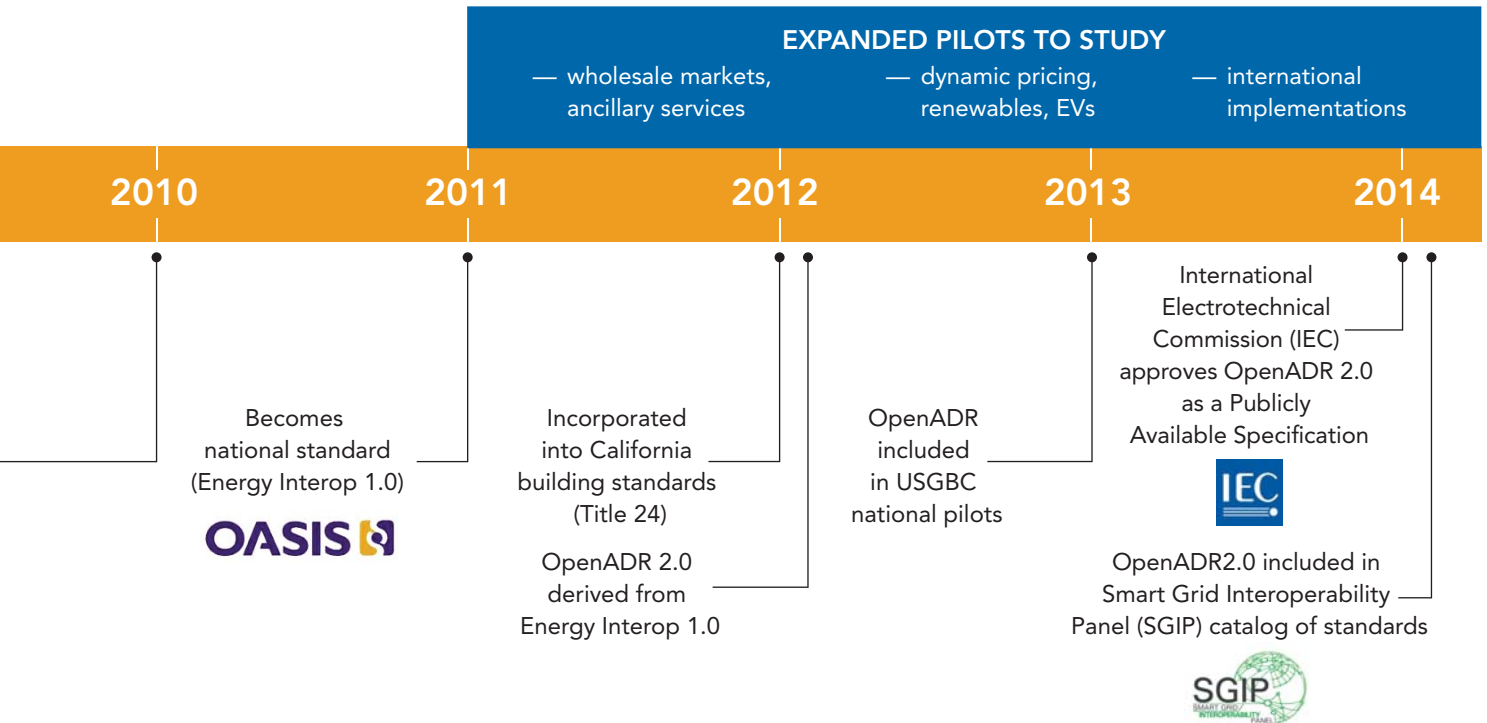


Research, Demonstration, and Market Facilitation Opportunities

Berkeley Lab began development of an open automated DR communication specification in 2002, even before the DRRRC was created. OpenADR allows buildings and facilities to reduce power consumption automatically. Using the Internet to convey these messages, OpenADR signals trigger preprogrammed strategies in building control systems. By 2013, OpenADR has provided approximately 250 MW of automated DR in California. While this is a small percentage of California’s total peak load, the opportunities to scale the technologies across different end-use sectors is significant.

Following successful field trials conducted from 2003 to 2006 , the California Public Utilities Commission mandated that all three investor-owned utilities in California offer OpenADR-based automated DR programs in 2007. Building control systems manufacturers and vendors quickly embraced OpenADR because of its simplicity, the short time it takes to develop products with it, and its ability to prepare their products for grid transactions. More than 100 companies support OpenADR and deploy technologies and automation products for residential, commercial, and industrial facilities through a variety of DR programs.

In response to early interest in OpenADR, the DRRRC donated the full communications specification to a standards-development organization in 2009. This was done so that OpenADR could begin the process of becoming a formal national standard, motivated by the National Institute of Standards and Technology (NIST) coordination of the Smart



Grid interoperability standards initiative. The resulting public standard, OpenADR version 2.0, is now widely used across the United States, and is gaining traction in several foreign countries. This standardization is important to improve cost-effective interoperability, and eventual applications within building codes. New control systems can be purchased with the native ability to receive DR signals from a utility or grid operator at a minimal cost.

In 2010, the OpenADR Alliance, a member-based nonprofit organization, was formed by Berkeley Lab, the DRRC, the Pacific Gas & Electric Company, the Southern California Edison Company, and Honeywell to foster the adoption of OpenADR. One of their first tasks was to establish a nationally recognized testing and certification program for manufactured products using the OpenADR 2.0 information exchange model. This effort was coordinated to help meet the U.S. Smart Grid interoperability goals¹.

Now that OpenADR 2.0 is a national standard, and is being considered for international standardization, its potential for mass deployment is significant. Utilities, ISOs, and regional transmission operators (RTOs) across the United States are encouraging the use of OpenADR to better manage supply and demand. OpenADR now has data models to facilitate wholesale markets, ancillary services, dynamic pricing, and distributed resources management through storage and local generation.



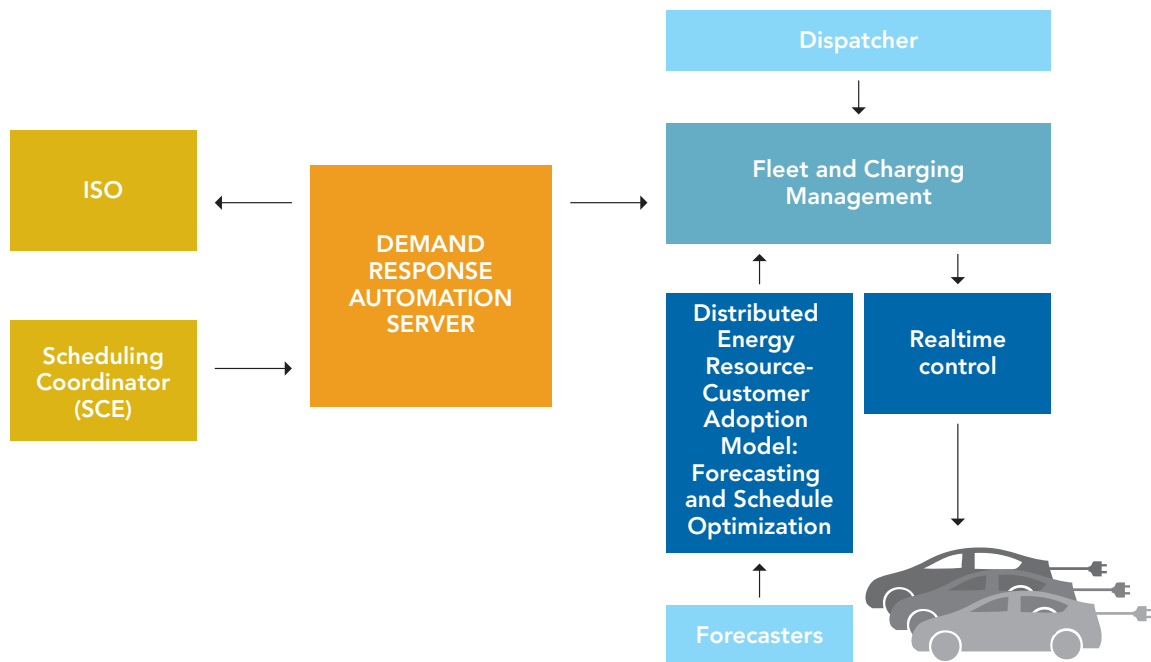
National and international OpenADR pilots and deployments.

Key Outcomes and Impacts

- The DRRC has received numerous industry awards recognizing the contributions from its OpenADR development work. OpenADR facilitates easy communication of DR signals, which enables consumer choice and interoperability among control equipment and new energy markets. OpenADR's nonproprietary, open standardized DR interface enables electricity providers to communicate DR signals directly to existing customers using a common language and existing communications such as the Internet.
- The DRRC led the development of OpenADR 1.0 specification, helped its commercial deployment, and advanced it to a formal national DR standard for the Smart Grid (OpenADR 2.0 element of the OASIS Energy Interop standard). OpenADR, now a foundational Smart Grid standard in the United States, is being considered for international Smart Grid pilot projects.
- The DRRC worked with a series of partners to establish a member-represented body, the OpenADR Alliance, for the adoption, testing, and certification of commercial OpenADR products. The Alliance now has more than 100 members, made up of electricity service providers, grid operators, research agencies, technology integrators, and energy-management companies from all end-use sectors (commercial, industrial, and residential).

1. See for example NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0, NIST Special Publication 11108R2, February 2012.

- The DRRC helped to develop the automated DR code language for adoption of DR in California's 2013 Title 24 building energy code adoption. OpenADR can support California's Title 24 code to provide the required standards-based messaging protocols.
- The DRRC continues to provide R&D and technical assistance with commercial and advanced OpenADR projects in the United States and internationally. OpenADR has been tested for end-to-end DR integration with retail and wholesale reliability and price responsive programs. OpenADR has been tested to provide fast, nonspinning reserves under California's participating load pilot, and later, with regulation services in intermittent renewable resources pilots. It is currently being used in a vehicle-to-grid demonstration at the Los Angeles Air Force Base. Recently, the DRRC successfully tested and demonstrated OpenADR to address variable generation and electric vehicles' integration with the grid.



LBNL's Distributed Energy Resource-Customer Adoption Model (DER-CAM) optimizes the charging and discharging of the Los Angeles Air Force Base's fleet of electric vehicles.

Issues and Next Steps

The DRRC continues to evaluate the role of OpenADR and open system communication platforms that interface with users to provide significant value to customers, systems operators, vendors, and regulators.

- As advanced and fast telemetry, communication, and measurement systems become cheaper and more reliable, wholesale DR markets are expected to grow. Research has begun at DRRC to examine how OpenADR can facilitate DR to be a viable competitor to supply-side generation systems.
- Changes in market structures (e.g., transactive energy networks) and in supply paradigms (e.g., distributed energy resources) will require new levels of communication support. DRRC is exploring how OpenADR or related communications platforms can play a role in coordinating resources and relaying critical price information in a timely way to support these new structures and paradigms.
- Many vendors who offer OpenADR servers or client-based technologies outside of the United States are conducting pilots to address localized DR needs. To aid these global deployments, OpenADR 2.0 is under consideration as an international standard by the International Electrotechnical Commission (IEC).

End-Use Load Control Strategies

Commercial and Residential Buildings

- **Problem:** In the United States, buildings account for 40% of total energy use, and nearly 70% of all electricity consumption. The U.S. Energy Information Administration notes that “nearly 40% of total U.S. energy consumption in 2012 was consumed in residential and commercial buildings, or about 40 quadrillion BTUs.” Cooling in both homes and commercial buildings is the main driver of peak demand in most regions of the United States.
- **Solution:** Research at the DRRC has shown that DR is an effective way to reduce electric loads in buildings during hot summer afternoons and, where electric heat is prevalent, during cold winter mornings. DRRC tools have identified DR strategies that are barely detectable to occupants, ensuring that DR becomes a way of doing business, not just a one-time test.
- **Benefit:** By reducing electrical peak loads at critical times, commercial and residential buildings can achieve significant economic and environmental benefits while helping to keep the lights on throughout the region.

Research, Demonstration, and Market Facilitation Opportunities

Building owners can save energy and money by participating in DR programs. The DRRC’s work to identify, evaluate, and document a variety of possible end-use load-control strategies to modify electric load shapes in commercial and residential buildings has been widely used throughout the country. Initial DRRC work concentrated on developing cooling control strategies for peak load reduction in commercial buildings on hot summer afternoons. More recently, DRRC research has grown to include new customer segments, with more flexible loads to explore DR options with varying response times and durations that can be dynamically controlled any time of day. The DRRC’s research on residential energy use has explored how the introduction of advanced meters can support DR when needed through dynamic pricing pilots and home automation capable of responding according to different control signals.

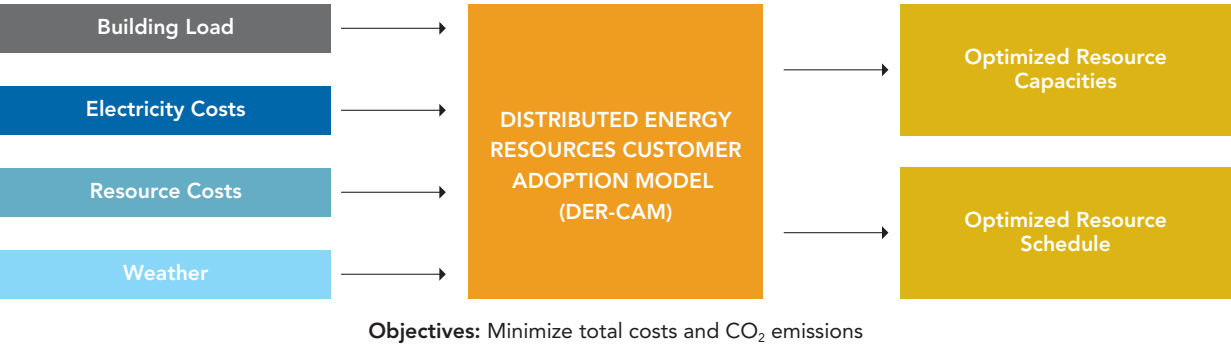
The DRRC’s Demand Response Quick Assessment Tool (DRQAT) has gained wide acceptance among the DR community. It uses an EnergyPlus model to enable users to predict energy and peak electrical demand savings, economic savings, and thermal comfort impact for various DR strategies. Initially, DRQAT was used to develop DR estimations to support automated DR deployments in utility programs at Southern California Edison and, later, at Pacific Gas & Electric Company. Now on its fifth version, it has been expanded to support DR in Canada, New York, and Hawaii. Recently, the DRRC developed a thermal-energy storage system model to evaluate the effect of DR control strategies in buildings with thermal storage systems. The Federal Energy Regulatory Commission’s National Action Plan recognizes DRQAT as a tool that customers, states, utilities, and DR providers can use to identify DR strategies.

Increasingly, buildings are supplementing their traditional electric supply with behind-the-meter distributed-energy resources such as rooftop solar photovoltaic systems. These can lead to intermittent strains on the grid from short-term overgeneration, and load forecast errors that can cause steep ramping demands in standby generation. The DRRC is examining how short-term changes in building operations with DR can mitigate the inherent intra-hour variability in those resources before they cause grid-scale problems. The DRRC has also been exploring ways to use OpenADR to coordinate building loads with local distribution systems to help solve some of the capacity and reliability issues.

Demand response can play a role in transitioning electric markets as well. The recent unexpected shutdown of San Onofre Nuclear Generating Station at the same time as the expected retirement of once-through cooling generation units has created grid capacity issues in Southern California that are expected to increase when warmer weather returns to the region. The DRRC is studying how DR can mitigate the capacity issues without requiring extensive construction of replacement generation.

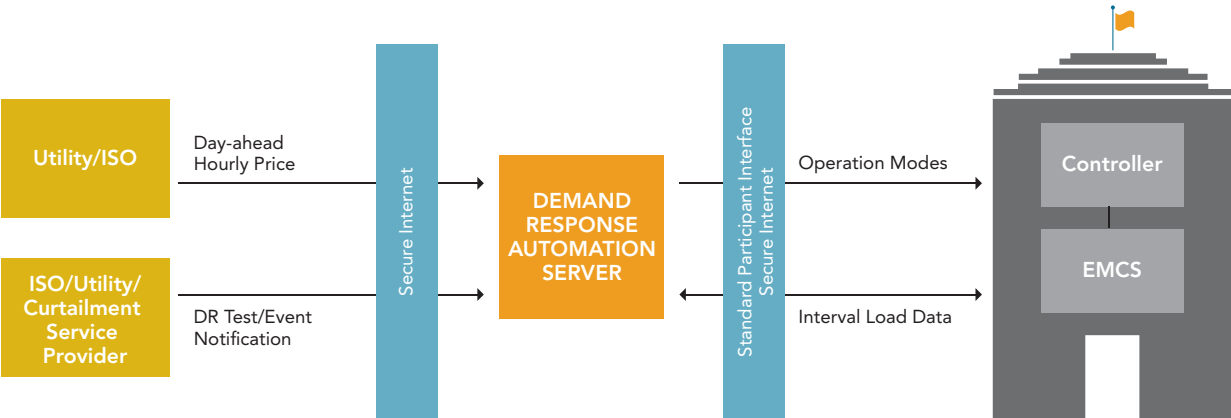
When DR analysis is conducted for a large number of buildings, decisionmakers need reliable tools to help coordinate and prioritize their investments. The DRRC has been working actively with:

- Various U.S. Navy facilities, where the DRRC analyzed the performance of more than 20 buildings enabled with two-stage DR strategies, and built on this experience to develop and apply prioritization methodologies to more than 200 buildings to help the Navy select the next 50 high-priority sites;
- Santa Rita Jail, in Dublin, CA, where the DRRC extended the previously developed Distributed Energy Resources Customer Adoption Model (DER-CAM) to incorporate DR decisions and various utility tariffs. This enabled the site to effectively coordinate among various distributed assets while capturing additional value from DR participation and finding a more cost-effective tariff; and
- The California Lighting Technology Center (CLTC), to facilitate the adoption of automated DR by lighting-controls companies and expand the use of OpenADR to reduce the cost of DR enablement.



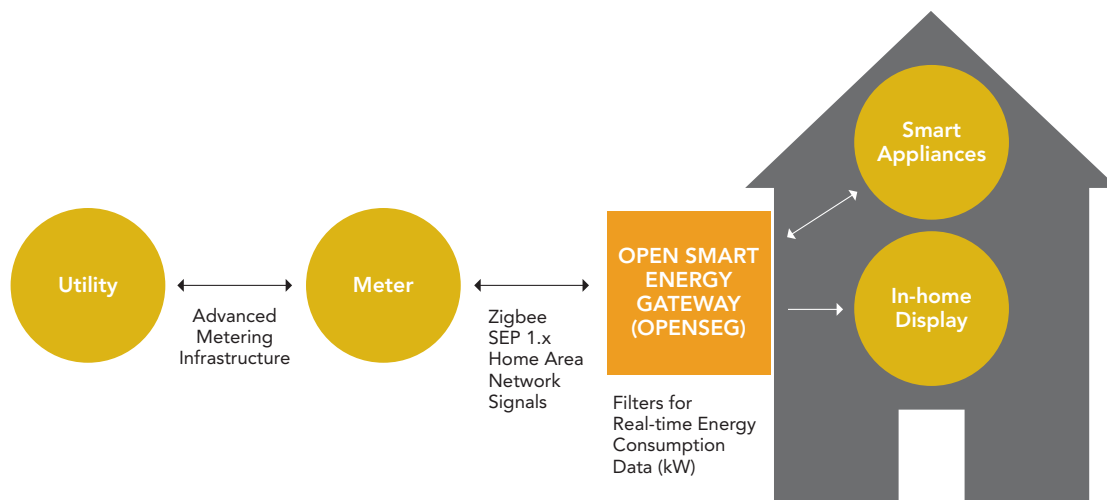
LBNL's DER-CAM optimizes operations based on real-time conditions to reduce emissions and costs.

The DRRC’s work outside California includes its collaboration with the New York State Energy Research and Development Authority (NYSERDA) to provide automation to enable customers to manage hourly pricing and peak electric demand charges by demonstrating how adopting OpenADR provides greater flexibility and controllability of DR. This project in New York City is evaluating the use of a new automation system platform with four commercial high-rise buildings to save energy and money with automated DR. The DRRC’s OpenADR information-exchange model is being used to facilitate continuous DR price response.



OpenADR communication architecture for the New York demonstration project.

Some residential customers are now equipped with smart meters containing home area network (HAN) radios that can relay near-real-time electricity consumption data and real-time prices. However, only a small number of the HAN radios have been turned on, resulting in missed opportunities for both energy providers and their residential customers. Research from the DRRC found that cyber security concerns are a large hindrance to their widespread use. The DRRC is designing an in-premise, customer-owned gateway to receive customer energy use from the utility via the meter's radio. Called the Open Smart Energy Gateway (OpenSEG), the DRRC design decouples the utility network from the home network while still providing a reliable, consistent interface to convey timely information to the home. This solution will let residents decide with whom they would like to share their meter data and choose whether (and how much) to participate in a utility's DR programs. The DRRC also demonstrated in the Berkeley Lab D2G Laboratory that the same infrastructure can be used to deliver low-cost telemetry data to third parties.



Open Smart Energy Gateway (OpenSEG) provides a secure common interface for conveying real-time consumption data to in-home displays and smart appliances.

Key Outcomes and Impacts

- Building operators can use DRRC's DRQAT to identify which DR strategies will provide the best energy and peak electrical demand savings, economic savings, and thermal comfort impacts, even across different climate zones.
- Prioritization of DR investments and investments in behind-the-meter assets and operations of these assets to minimize utility cost is a growing area of research. Operators of buildings with significant distributed energy resources can utilize DR DER-CAM to plan and operate their DER systems to achieve maximum benefits from their investments.
- Lighting is a flexible resource and a huge potential opportunity for California. The DRRC continues to investigate how to reduce the cost of automated DR for lighting systems.
- The OpenADR demonstration project in New York showed that OpenADR can be used to continuously and automatically manage building loads to respond to dynamic pricing while providing building operators with flexibility in their decision making using appropriate controls.
- In residential DR research, DRRC determined that because other communication channels with more reliable security and bandwidth can convey price and event data, the radio from the meter only needs to communicate simple meter data to the gateway, which in turn can translate that information for communication to devices using a variety of privately developed home network protocols.

Issues and Next Steps

The past year has seen a growing interest in DRQAT to estimate DR potential in buildings, and to develop it to include other climates and regions as well as other building types. As a result, the DRRC will expand it to simulate cold-storage facilities, to include optimization of behind-the-meter assets, as well as continued evaluation of thermal-energy storage for commercial buildings.

For the OpenADR demonstration in New York City, the DRRC project team is currently developing a dynamic load-optimization algorithm using day-ahead hourly prices and real-time feedback from building systems. The efficacy of locating intelligence within the facility versus in the cloud as well as its implications for site security will be evaluated and are expected to be useful in a variety of other settings.

DRRC's OpenSEG will be tested in field trials to better understand how consumers are able to use their own real-time consumption data to better participate in utility DR programs.

Industrial, Agriculture, and Water

- **Problem:** While the Industrial, Agriculture and Water (IAW) sector holds the potential for widespread DR participation, there are a number of challenges, such as the wide variation in loads and processes across and within sectors, resource-dependent loading patterns driven by customer orders or time-critical processing, user perceptions of a lack of control in the automated process, and aversion to risk—especially unscheduled downtime.
- **Solution:** DRRC has identified processes in which the potential for DR is significant, and we have used these industrial loads to test and demonstrate DR strategies that can serve as reference points for future work.
- **Benefit:** By expanding the focus of DR to include industrial processes, the DRRC expanded the extent to which DR contributes to grid stability around the clock.

Research, Demonstration, and Market Facilitation Opportunities

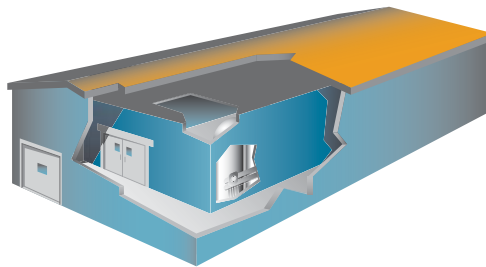
In 2006, the DRRC formed an Industrial Demand Response Team to focus on the IAW sector. Through research and case studies, the team has examined the feasibility of IAW DR strategies, with an emphasis on technical and economic evaluation, and worked to encourage more widespread implementation of these strategies.

Toward this objective, the DRRC team focused on the implementation of DR, OpenADR, and energy management in IAW sectors previously identified as having good potential for DR: wastewater treatment, refrigerated warehouses, data centers, and agricultural irrigation. Within the IAW context, the team studies the interrelationship between DR and energy management, including its connections to improving energy efficiency; implementation of DR with shorter notice and shorter duration; and the potential to participate in ancillary services through reliable, fast-response DR.

In keeping with the DRRC's objective of maintaining active collaboration with industry, the team is a subcontractor to AutoGrid, a venture-backed California-based startup that has developed a DR optimization and management platform under an Advanced Research Projects Agency-Energy (ARPA-E) and California Energy Commission (CEC) co-funded project. Working with the AutoGrid team at the Sunnyvale Water Pollution Control Plant, the DRRC team provides critical technical guidance, site characterization, test planning, testing, recommendations to enable DR on various timescales (including rules to achieve financial optimization), and advice on how to evaluate DR deployment performance. To date, the project has begun to demonstrate how these facilities can participate in not only the traditional DR programs targeted at reducing peak demand, but also the new and emerging DR programs designed to provide fast-responding ancillary services to the grid to support large-scale integration of renewable generation. This project is expected to serve as a reference for other wastewater treatment and industrial plants consuming a significant amount of electricity in California and is expected to be performed at other IAW sites in the future.

The DRRC team has also been developing tools and that can be used for assessment, evaluation, and outreach of DR in target sectors.

- A tool is being developed to provide PG&E personnel with a consistent way to estimate the achievable load from agricultural irrigation pumping sites. A companion tool will be built with a customer-oriented Web-facing interface, giving prospective DR participants an idea of their response capability, and potential incentives for their participation.
- A DR Strategy Guide and accompanying software tool (both being developed by VaCom Technologies with input from the DRRC team) will soon be completed and are expected to provide a comprehensive road map to aid refrigerated warehouse facility managers in determining how, and whether, to implement energy efficiency and DR strategies in their facilities, how to do so, and what the expected benefits might be.



DRRC plans to explore the DR potential of refrigerated warehouses, using the cold mass as a form of energy storage.

Key Outcomes and Impacts

- The DRRC has evaluated the energy efficiency and DR potential and performed case studies showing the DR potential of:
 - Individual wastewater treatment plants
 - Selected refrigerated warehouses, where the research lead to a preliminary strategy guide
 - Active data centers
- The DRRC team has also characterized the ability of different agricultural irrigation end-use loads to participate in demand response.
- The DRRC team assessed the capacity of control systems and automation for California industries to assist policymakers and industry in meeting the challenges of real-time pricing and recommended IAW sector focus for DR and AutoDR.
- DRRC work in this area has led to a report on synergies between energy management and DR in the industrial context, based on what was learned through case studies of Energy Management System adoptions at a fertilizer plant and a carpet manufacturing facility.

Issues and Next Steps

The DRRC IAW team continues to explore the DR capabilities of its target industries, and is working to identify additional sectors and processes with DR potential. It is also working to further the use of automated DR in industry, and is investigating the ability of industrial facilities using automated DR to participate in the fast-response ancillary services market. Additional work is expected in these areas:

- Developing a DRQAT-like tool that can make accurate recommendations about energy efficiency and DR potential in individual refrigerated warehouses.
- Developing an interactive online DR Strategy Guide for use in the agricultural irrigation sector to provide growers a more comprehensive analysis of the cost-saving opportunities from implementing DR and energy-efficiency strategies.
- In the wastewater treatment sector, comprehensively assessing the potential for improving overall energy performance in treatment plants, using both mature and emerging technologies; and to develop reports, guides, and tools that can help this sector identify additional ways to use energy more cost effectively.

Demand Response Research Center (DRRC)

Over the past decade, the DRRC has developed and deployed new technology, guides, demonstrations, and knowledge to assist California, the United States, and international partners in reducing peak demand and automating DR. As load changes geographically and over time, automated DR, communicated using the DRRC-developed OpenADR, can provide quick load changes needed to match supply from variable generation systems. Currently, the DRRC is studying the technology and resources to support increasingly faster DR (from day-ahead to minutes-ahead notification prior to required response) for new market needs. Fast DR means that end-use loads can use advances in telemetry to match demand and supply sides of the grid more quickly, which will encourage the growth of inherently variable renewable energy resources. The DRRC is also studying how DR can facilitate the growing adoption of distributed energy resources by improving their coordination with the needs of the grid. With the help of open platforms to provide interoperability and integration of demand-side resources—developed through DRRC research—wholesale coordination of resources is expected to provide rapid response capability to improve and maintain grid stability beyond what is possible today.

References for the History of Demand Response

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Appendix A. DRRC Publications from 2009–2013

To access these publications, go to drcc.lbl.gov/sites/drcc.lbl.gov/files/lbnl-xxx.pdf (replacing “xxx” with the LBNL report number). For example: drcc.lbl.gov/sites/drcc.lbl.gov/files/lbnl-6155e.pdf.

Energy Technologies and Systems Integration

LBNL Report Number*	Citation
LBNL-6055E	Holmberg, David G., Girish Ghatikar, Edward L. Koch, and Jim Boch. 2012. OpenADR Advances. <i>ASHRAE Journal</i> 54 (11).
LBNL-6016E	Ghatikar, Girish, and Ed Koch. 2012. Deploying Systems Interoperability and Customer Choice within Smart Grid. In <i>Grid-Interop 2012</i> . Irving, Texas.
LBNL-5064E	McParland, Charles. 2011. OpenADR Open Source Toolkit: Developing Open Source Software for the Smart Grid. In <i>2011 IEEE Power & Energy Society General Meeting</i> . Detroit, Michigan.
LBNL-5379E	Koch, Ed, and Sila Kiliccote. 2011. Role of Standard Demand Response Signals for Advanced Automated Aggregation. In <i>Grid-Interop 2011</i> . Phoenix, Arizona.
LBNL-5273E	Ghatikar, Girish, and Rolf Bienert. 2011. Smart Grid Standards and Systems Interoperability: A Precedent with OpenADR. In <i>Grid-Interop 2011</i> . Phoenix, Arizona.
LBNL-3921E	Ghatikar, Girish, Johanna L. Mathieu, Mary Ann Piette, Ed Koch, and Dan Hennage. 2010. Open Automated Demand Response Dynamic Pricing Technologies and Demonstration.
LBNL-4028E	Ghatikar, Girish, Johanna L. Mathieu, Mary Ann Piette, and Sila Kiliccote. 2010. Open Automated Demand Response Technologies for Dynamic Pricing and Smart Grid. In <i>Grid-Interop Conference 2010</i> . Chicago, Illinois.
LBNL-1779E	Piette, Mary Ann, Girish Ghatikar, Sila Kiliccote, Ed Koch, Dan Hennage, Peter Palinsky, and Charles McParland. 2009. Open Automated Demand Response Communication Specification (Version 1.0).
LBNL-2750E	Lutzenhiser, Susan, Jane Peters, Mithra Moezzi, and James Woods. 2009. Beyond the Price Effect in Time-of-Use Programs: Results from a Municipal Utility Pilot, 2007–2008. In <i>International Energy Program Evaluation Conference 2009</i> . Portland, Oregon.
LBNL-2294E	Rubinstein, Francis, Girish Ghatikar, Jessica Granderson, Paul Haugen, Carlos Romero, and David Watson. 2009. Barrier Immune Radio Communications for Demand Response.
LBNL-2905E	Koch, Ed, and Mary Ann Piette. 2009. Direct versus Facility Centric Load Control for Automated Demand Response. In <i>Grid-Interop Forum 2009</i> . Denver, Colorado.
LBNL-2945E	Kiliccote, Sila, Mary Ann Piette, Girish Ghatikar, Ed Koch, Dan Hennage, John Hernandez, Albert Chiu, Osman Sezgen, and John Goodin. 2009. Open Automated Demand Response Communications in Demand Response for Wholesale Ancillary Services. In <i>Grid-Interop Forum 2009</i> . Denver, Colorado.
LBNL-2489E	Heffner, Grayson. 2009. Demand Response Valuation Frameworks Paper.

Buildings

LBNL Report Number*	Citation
LBNL-6369E	Ghatikar, G., V. Ganti, and C. Basu. 2013. Expanding Buildings-to-Grid (B2G) Objectives in India. August.
LBNL-6013E	Searle, Justin, and Chuck McParland. 2012. HAN Attack Surface and the Open Smart Energy Gateway Project.
LBNL-6216E	Piette, Mary Ann, Sila Kiliccote, and Junqiao H. Dudley. 2012. Field Demonstration of Automated Demand Response for Both Winter and Summer Events in Large Buildings in the Pacific Northwest. <i>Energy Efficiency</i> (Special Issue on Smart Grids and Energy Efficiency).
LBNL-5894E	Piette, Mary Ann, Jessica Granderson, Michael Wetter, and Sila Kiliccote. 2012. Intelligent Building Energy Information and Control Systems for Low-Energy Operations and Optimal Demand Response. <i>IEEE Design and Test of Computers</i> 29 (4):8–16.
LBNL-5662E	Piette, Mary Ann, Jessica Granderson, Michael Wetter, and Sila Kiliccote. 2012. Responsive and Intelligent Building Information and Control for Low-Energy and Optimized Grid Integration. In <i>ACEEE 2012 Summer Study on Energy Efficiency in Buildings</i> . Pacific Grove, California.
LBNL-6014E	Kiliccote, Sila, Mary Ann Piette, James Fine, Oren Schetrit, Junqiao H. Dudley, and Heather Langford. 2012. LEED Demand Response Credit: A Plan for Research towards Implementation. In <i>2012 Greenbuild Conference & Expo</i> . San Francisco, California.
LBNL-5560E	Addy, Nathan, Sila Kiliccote, Johanna Mathieu, and Duncan S. Callaway. 2012. Understanding the Effect of Baseline Modeling Implementation Choices on Analysis of Demand Response Performance. In <i>ASME 2012 International Mechanical Engineering Congress & Exposition</i> . Houston, Texas.
LBNL-5057E	Price, Philip, Johanna Mathieu, Sila Kiliccote, and Mary Ann Piette. 2011. Using Whole-Building Electric Load Data in Continuous or Retro-Commissioning. In <i>National Conference on Building Commissioning</i> .
LBNL-4982E	Page, Janie, Sila Kiliccote, Junqiao Han Dudley, Mary Ann Piette, Albert Chiu, Bashar Kellow, Ed Koch, and Paul Lipkin. 2011. Automated Demand Response Technology Demonstration Project for Small and Medium Commercial Buildings.
LBNL-4944E	Mathieu, Johanna L., Phillip N. Price, Sila Kiliccote, and Mary Ann Piette. 2011. Quantifying Changes in Building Electricity Use, with Application to Demand Response. <i>IEEE Transactions on Smart Grid</i> 2 (3):507–518.
LBNL-5096E	Mathieu, Johanna L., Duncan S. Callaway, and Sila Kiliccote. 2011. Examining Uncertainty in Demand Response Baseline Models and Variability in Automated Response to Dynamic Pricing. In <i>2011 IEEE Conference on Decision and Control and European Control Conference</i> . Orlando, Florida.
LBNL-5129E	Mathieu, Johanna L., Duncan S. Callaway, and Sila Kiliccote. 2011. Variability in Automated Responses of Commercial Buildings and Industrial Facilities to Dynamic Electricity Prices. <i>Energy and Buildings</i> 43 (12):3322–3330.

Buildings

LBNL Report Number*	Citation
LBNL-3636E	Yin, Rongxin, Sila Kiliccote, Mary Ann Piette, and Kristen Parrish. 2010. Scenario Analysis of Peak Demand Savings for Commercial Buildings with Thermal Mass in California. In <i>2010 ACEEE Summer Study on Energy Efficiency in Buildings</i> . Pacific Grove, California.
LBNL-4190E	Rubinstein, Francis, Li Xiaolei, and David S. Watson. 2010. Using Dimmable Lighting for Regulation Capacity and Non-Spinning Reserves in the Ancillary Services Market. A Feasibility Study.
LBNL-3713E	Price, Phillip. 2010. Methods for Analyzing Electric Load Shape and its Variability.
LBNL-3643E	Kiliccote, Sila, Mary Ann Piette, Johanna Mathieu, and Kristen Parrish. 2010. Findings from Seven Years of Field Performance Data for Automated Demand Response in Commercial Buildings. In <i>2010 ACEEE Summer Study on Energy Efficiency in Buildings</i> . Pacific Grove, California.
LBNL-2573E-FINAL	Kiliccote, Sila, Mary Ann Piette, and Junqiao Dudley. 2010. Northwest Open Automated Demand Response Technology Demonstration Project.
LBNL-3644E	Dudley, Junqiao Han, Doug Black, Mike Apte, Mary Ann Piette, and Pam Berkeley. 2010. Comparison of Demand Response Performance with an EnergyPlus Model in a Low Energy Campus Building. In <i>2010 ACEEE Summer Study on Energy Efficiency in Buildings</i> . Pacific Grove, California.
LBNL-2340E	Piette, Mary Ann, Girish Ghatikar, Sila Kiliccote, David Watson, Ed Koch, and Dan Hennage. 2009. Design and Operation of an Open, Interoperable Automated Demand Response Infrastructure for Commercial Buildings. <i>Journal of Computing Science and Information Engineering</i> 9(2) 2.
LBNL-2573E	Kiliccote, Sila, Mary Ann Piette, and Junqiao Han Dudley. 2009. Northwest Open Automated Demand Response Technology Demonstration.
LBNL-2195E	Kiliccote, Sila, June Dudley, Mary Ann Piette, Ed Koch, and Dan Hennage. 2009. Open Automated Demand Response for Small Commercial Buildings.
LBNL-2742E	Herter, Karen, Seth Wayland, and Josh Rasin. 2009. Small Business Demand Response with Communicating Thermostats: SMUD's Summer Solutions Research Pilot.
LBNL-2743E	Herter, Karen, Seth Wayland, and Josh Rasin. 2009. A Successful Case Study of Small Business Energy Efficiency and Demand Response with Communicating Thermostats. In <i>International Energy Program Evaluation Conference 2009</i> . Portland, Oregon.
LBNL-2753E	Granderson, Jessica, Junqiao Han Dudley, Sila Kiliccote, and Mary Ann Piette. 2009. Chilled Water Thermal Storage System and Demand Response at the University of California at Merced. In <i>9th International Conference for Enhanced Building Operations</i> . Austin, Texas.
LBNL-4984E	Coughlin, Katie, Mary Ann Piette, Charles Goldman, and Sila Kiliccote. 2009. Statistical Analysis of Baseline load models for Non-Residential Buildings. <i>Energy and Buildings</i> 41 (4):374–381. doi:10.1016/j.enbuild.2008.11.002.

Industrial, Agriculture, and Water

LBNL Report Number*	Citation
LBNL-6108E	Marks, Gary, Edmund Wilcox, Daniel Olsen, and Sasank Goli. 2013. Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study.
LBNL-5750E	Scott, Doug, Ryan Hoest, Fei Yang, Sasank Goli, and Daniel Olsen. 2012. The Impact of Control Technology on the Demand Response Potential of California Industrial Refrigerated Facilities Final Report.
LBNL-5719E	Olsen, Daniel, Sasank Goli, and Aimee McKane. 2012. Examining Synergies between Energy Management and Demand Response: A Case Study at Two California Industrial Facilities.
LBNL-6056E	Olsen, Daniel, Sasank Goli, David Faulkner, and Aimee McKane. 2012. Opportunities for Automated Demand Response in Wastewater Treatment Facilities in California—Southeast Water Pollution Control Plant Case Study.
LBNL-5319E	Ghatikar, Girish, Aimee McKane, Sasank Goli, Peter Therkelsen, and Daniel Olsen. 2012. Assessing the Control Systems Capacity for Demand Response in California Industries.
LBNL-5763E	Ghatikar, Girish, Venkata Ganti, Nance Matson, and Mary Ann Piette. 2012. Demand Response Opportunities and Enabling Technologies for Data Centers: Findings From Field Studies.
LBNL-6104E	Ganti, Venkata, and Girish Ghatikar. 2012. Smart Grid as a Driver for Energy-Intensive Industries: A Data Center Case Study. In <i>Grid-Interop 2012</i> . Irving, Texas.
LBNL-5680E	Goli, Sasank, Daniel Olsen, Aimee McKane, and Mary Ann Piette. 2011. 2008–2010 Research Summary: Analysis of Demand Response Opportunities in California Industry.
LBNL-4837E	Goli, Sasank, Aimee McKane, and Daniel Olsen. 2011. Demand Response Opportunities in Industrial Refrigerated Warehouses in California. In <i>2011 ACEEE Summer Study on Energy Efficiency in Industry</i> . Niagara Falls, New York.
LBNL-3889E	Thompson, Lisa, Alex Lekov, Aimee McKane, and Mary Ann Piette. 2010. Opportunities for Open Automated Demand Response in Wastewater Treatment Facilities in California—Phase II Report. San Luis Rey Wastewater Treatment Plant Case Study.
LBNL-4849E	Olsen, Daniel, Sasank Goli, David Faulkner, and Aimee McKane. 2010. Opportunities for Energy Efficiency and Demand Response in the California Cement Industry.
LBNL-3047E	Ghatikar, Girish, Mary Ann Piette, Sydney Fujita, Aimee McKane, Junqiao Han Dudley, Anthony Radspieler Jr., K. C. Mares, and Dave Shroyer. 2010. Demand Response and Open Automated Demand Response Opportunities for Data Centers.
LBNL-1244E	Lisa Thompson, Katherine Song, Alex Lekov, and Aimee McKane. 2009. Automated Demand Response Opportunities in Wastewater Treatment Facilities.
LBNL-2585E	Lewis, Glen, Ivin Rhyne, and Barbara Atkinson. 2009. California Food Processing Industry Wastewater Demonstration Project: Phase I Final Report.

Industrial, Agriculture, and Water

LBNL Report Number*	Citation
LBNL-2572E	Lekov, Alex, Lisa Thompson, Aimee McKane, Katherine Song, and Mary Ann Piette. 2009. Opportunities for Energy Efficiency and Open Automated Demand Response in Wastewater Treatment Facilities in California—Phase I Report.
LBNL-1991E	Lekov, Alex, Lisa Thompson, Aimee McKane, Alexandra Rockoff, and Mary Ann Piette. 2009. Opportunities for Energy Efficiency and Automated Demand Response in Industrial Refrigerated Warehouses in California.

Technology to support changes in electric markets

LBNL Report Number*	Citation
LBNL-4189E	Kiliccote, Sila, Pamela Sporborg, Imran Sheik, Erich Huffaker, and Mary Ann Piette. 2010. Integrating Renewable Resources in California and the Role of Automated Demand Response.
LBNL-6155E	Cappers, Peter, Jason MacDonald, and Charles Goldman. 2013. Market and Policy Barrier for Demand Response Providing Ancillary Services in U.S. Markets.
LBNL-6215E	Levy, Roger, and Sila Kiliccote. 2013. Hawaiian Electric Company Demand Response Roadmap Project Final Report.
LBNL-5555E	Watson, David S., Nance Matson, Janie Page, Sila Kiliccote, Mary Ann Piette, Karin Corfee, Betty Seto, Ralph Masiello, John Masiello, Lorin Molander, Samuel Golding, Kevin Sullivan, Walt Johnson, and David Hawkins. 2012. Fast Automated Demand Response to Enable the Integration of Renewable Resources.
LBNL-5578E	Shen, Bo, Chun Chun Ni, Girish Ghatikar, and Lynn Price. 2012. What China Can Learn from International Experiences in Developing a Demand Response Program. In <i>ECEEE Summer Study on Energy Efficiency in Industry</i> . Arnhem, Netherlands.
LBNL-5580E	Shen, Bo, Girish Ghatikar, Chun Chun Ni, Junqiao Dudley, Phil Martin, and Greg Wikler. 2012. Addressing Energy Demand through Demand Response: International Experiences and Practices.
LBNL-5958E	MacDonald, Jason, Peter Cappers, Duncan Callaway, and Sila Kiliccote. 2012. Demand Response Providing Ancillary Services: A Comparison of Opportunities and Challenges in the US Wholesale Markets. In <i>Grid-Interop 2012</i> . Irving, Texas.
LBNL-5557E	Kim, Joyce Ji Hyun, and Sila Kiliccote. 2012. Price Responsive Demand in New York Wholesale Electricity Market using OpenADR.
LBNL-5556E	Kiliccote, Sila, Phil Price, Mary Ann Piette, Geoffrey Bell, Steve Pierson, Edward Koch, Jeremy Carnam, Hugo Pedro, John Hernandez, and Albert Chiu. 2012. Field Testing of Automated Demand Response for Integration of Renewable Resources in California's Ancillary Services Market for Regulation Products.

Appendix B. Partners, Funding Agencies, and Cost-Share Partners

The Demand Response Research Center works with a variety of private industry; power providers; and local, state, and federal government partners to develop new technologies, tools, policies, and standards, and to conduct the demonstrations that bring demand-response innovations to market.

- Akuacom
- Alameda County
- AutoGrid
- Bonneville Power Administration (BPA)
- CIEE
- Contra Costa County
- Electric Power Research Institute
- California Energy Commission (CEC)
- California Public Utilities Commission (CPUC)
- Environmental Security Technology Certification Program
- Honeywell Building Solutions
- International Electrotechnical Commission
- IP Keys
- Los Angeles Air Force Base
- NEC Labs America
- National Institute of Standards and Technology
- Natural Resource Canada's Canmet ENERGY
- New York State Energy Research and Development Authority
- NV Energy
- OpenADR Alliance
- Olivine
- Organization for the Advancement of Structured Information Standards
- Pacific Gas & Electric
- Power Standards Lab
- Sacramento Municipal Utility District
- San Diego Gas & Electric
- Seattle City Light
- Smart Grid Interoperability Panel
- Southern California Edison
- UCA International Users Group?
- University of New Mexico
- U.S. Air Force
- U.S. Department of Defense
- US Navy
- US Green Building Coalition
- Utility Integration Solutions

Funding for the Demand Response Research Center activities has been provided by the following entities:

- California Energy Commission—DRRC's founding funding agency
- California Public Utility Commission
- Electric Power Research Institute (EPRI)
- Hawaiian Electric Company (HECO)

- Honeywell
- Intel Federal
- Japan Advanced Hightechnology Research Center (AHRI)
- Korea Electrotechnology Research Institute (KERI)
- Korea Micro Energy Grid (K-MEG)
- Korea Telecom (KT)
- Natural Resource Canada's Canmet ENERGY
- New York State Energy Research and Development Authority (NYSERDA)
- Pacific Controls
- Pacific Gas and Electric
- Sacramento Municipal Utility District
- San Diego Gas and Electric
- Southern California Edison
- U.S. Department of Defense, Environmental Security Technology Certification Program (ESTCP)
- U.S. Department of Energy
 - Advanced Research Projects Agency – Energy (ARPA-E)
 - Bonneville Power Authority (BPA)
 - Office of Electricity Delivery and Energy Reliability (OE)
 - Energy Efficiency and Renewable Energy (EERE)
 - EERE Building Technologies Office (BTO)
 - EERE International Programs
- U.S. Green Buildings Council

Appendix C. Acronyms

ARPA-E	Advanced Research Projects Agency-Energy
CEC	California Energy Commission
DR	demand response
DRRC	Demand Response Research Center
DER	distributed energy resource
CLTC	California Lighting Technology Center
D2G	Demand to Grid
DER-CAM	Distributed Energy Resources Customer Adoption Model
DRQAT	Demand Response Quick Assessment Tool
IEC	International Electrotechnical Commission
HAN	home area network
IAW	Industrial, Agriculture, and Water
ISO	Independent System Operator
NIST	National Institute of Standards and Technology
NYYSERDA	New York State Energy Research and Development Authority
OpenADR	Open Automated Demand Response
OpenSEG	Open Smart Energy Gateway
RTO	regional transmission operator



